Enabling Breakthrough Kinetic Simulations of the Magnetosphere Using Petascale Computing

The ultimate goal in space physics is to understand how solar wind transfers its mass, momentum, and energy to the magnetosphere—the highly magnetized region around the Earth. This deceptively simple subject has kept scientists at bay for over 50 years.

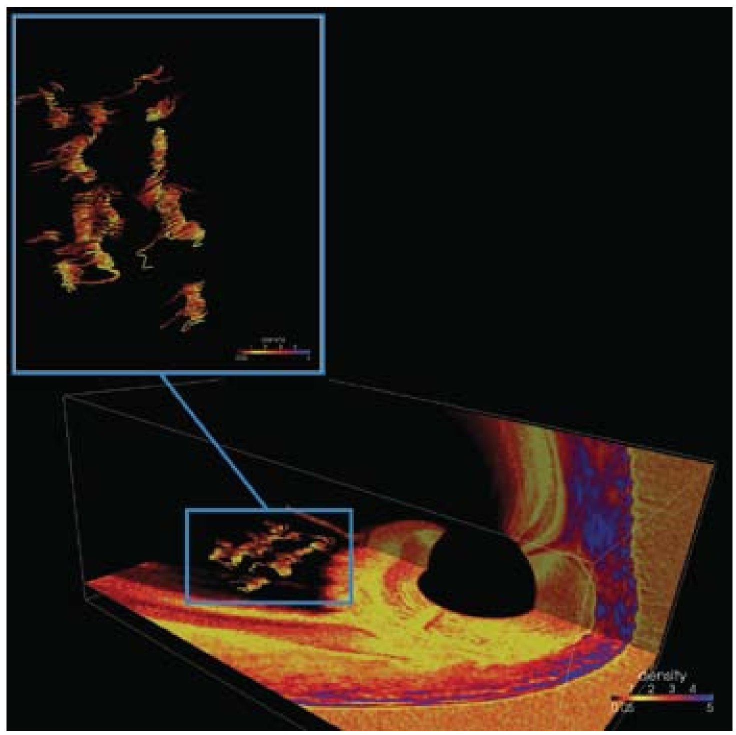
The interaction of solar wind with Earth's magnetosphere is more complex than originally thought. A major reason for this complexity is the dominance of ion kinetic effects that occur on relatively small ion scales but affect the large-scale dynamics of the magnetosphere. Given this complexity, numerical simulations are at the forefront of modeling efforts.

The objectives of our work are to understand the interaction of solar wind with the Earth and planetary magnetospheres and how solar wind controls the flow of energy and momentum throughout the system. We combine our recent innovations in hybrid simulations and the power of petascale computing to make breakthrough, 3D global kinetic simulations of the magnetosphere.

Recent observations from the CLUSTER mission (a European Space Agency unmanned space mission to study Earth's magnetosphere) show that during geomagnetically disturbed times, the O+ ion number density in the plasma sheet close to the reconnection X-line in Earth's magnetotail can become comparable to, or even higher than, the corresponding H+ ion number density, and that the O+ ions carry most of the particle pressure. We are using state-of-the-art full particle simulations to understand the effects of oxygen on the reconnection process.

We have performed the largest (450x450 ion inertial length) 2D simulations of reconnection to date, enabled by a large number of processors and the Pleiades supercomputer. Our study will provide insight into the details of the reconnection process in the presence of O+, a subject where almost no theoretical work exists. This work on global hybrid simulations is providing a first glimpse at the kinetic structure and properties of large-scale phenomena such as flux transfer events.

Progress in space weather is expected to become even more urgent as human activity in near-Earth environments (for example, the number of active satellites and planned continuous human presence on the International Space Station) further accelerate.



Formation of flux ropes and plasmoids in the Earth's magnetotail, created by pressure from the solar wind on Earth's magnetosphere.

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